THE FUTURE OF OBSERVATIONAL STELLAR ATMOSPHERES

L. V. KUHI*

Institut d'Astrophysique, Paris, France

1. Introduction

The title of this talk is, of course, a bit absurd since no one in his right mind can possibly predict what will happen in the future over even one year let alone ten. However nothing is impossible for Dick Thomas and having accepted his invitation to present this talk I have to pretend to have a crystal ball and put up a good front. I think that the best way to proceed would be to look at the past few years in observational stellar atmospheres and point out some of the highlights, especially those advances which seem to hold great promise for our understanding of stellar atmospheres in the future. The observer's work falls neatly into two categories: the collection of data and their subsequent interpretation. The former involves the development and use of instrumentation (usually some type of spectrograph with a photon detection system); the latter is so closely linked to theory that it would be impossible to discuss it without recourse to theoretical assumptions and results. Therefore I would like to first mention a few instrumental developments which I consider to be of great importance and then discuss briefly some of the problems to which they might be applied in the next several years.

2. Instrumentation

There has been a great deal of activity over the past several years in extending the wavelength range of the observed spectrum as well as increasing the sensitivity of the instrumentation. The extension in wavelength range has come about because of two parallel trends: (1) the development of suitable detectors (e.g. the far infrared) and (2) the increased use of balloons, rockets and satellites to get above the Earth's atmosphere to observe the ultraviolet, (both near and far) as well as X-rays. Many remarkable and unexpected discoveries have been made because of this extension in wavelength and we can cite the P Cyg type profiles in the ultraviolet resonance lines of early type supergiants as a good example. In addition the longer baseline in wavelength provides a much better check on the accuracy of model atmospheres especially with regard to opacity sources and line-blanketing as witnessed by the emergent flux distribution. There is no doubt that this spectral interval will continue to pay large dividends in the future and we will return to some of the possibilities later in the talk.

The more efficient use of the radiation after it has been collected has also received considerable attention because of the extravagant waste of photons and/or observing time usually encountered with normal high dispersion spectroscopy and because of the

* On leave from the University of California, Berkeley.

Contopoulos (ed.), Highlights of Astronomy, 121–132. *All Rights Reserved*

https://doi.org/10.1017/S1539299600001866 Published online by Cambridge University Press

natural desire to observe even fainter objects at moderate dispersions. Fabry-Pérot and Michelson interferometers have found increasing use in the study of emission line spectra and interstellar absorption spectra in the optical and of absorption and emission spectra in the infrared. Their big advantage is the lack of an entrance slit with its resultant huge light loss at high dispersion (i.e. a few Å mm^{-1}) but very little application has yet been made to ordinary stellar spectroscopy in the optical. This should be a useful area to exploit in the future for obtaining highly accurate absorption line profiles for comparison with the results from model atmospheres. Another method of obtaining accurate line profiles has been that of photoelectric scanning at the focus of a suitable spectrograph with either a single or multi-slit arrangement to take advantage of the inherently higher accuracy of photoelectric devices compared to photographic plates. However because of their sequential operation (most such scanners can sample only a few spectral regions at a time) they are very inefficient in spite of their higher quantum efficiency. The extreme example of a multislit device is Oke's primefocus scanner which employs 16 photomultipliers behind 16 adjustable slits and enables the rapid determination of spectral energy distributions of very faint stars. However it is not suitable for the determination of accurate line profiles. Image tubes have also been widely used but their gains in the blue are not outstanding; however the gain over photographic plate gets progressively better with increasing wavelength although their photometric properties leave a great deal to be desired.

The major advances have come from the development of instrumentation involving special types of devices such as image dissector photomultipliers, vidicons, silicon diodes, etc. Here the gains over conventional techniques are enormous and the potential for stellar atmospheres (as well as other areas, of course) should be equally enormous for both high and low dispersion spectroscopy. There are a large variety of different systems in various stages of development and use at the present time and a brief description of three of these would give us some idea of how potentially useful they really are. The first of these is the SEC vidicon system developed by Lowrance and coworkers at Princeton which has been used successfully by Morton at a resolution of 0.75 Å over a small spectral range: $\lambda 4270$ to $\lambda 4495$ to study a 16.6 mag. quasar, PHL 957. The system has a 25×25 mm storage target with an inherent resolution of 25 μ and the ability to integrate for many hours. The quasar required 6 h of integration to get a signal-to-noise ratio of 20 and a background of only 1% of the maximum dynamic range. The transfer function is non-linear so that calibration at a range of intensity levels is required. However it can operate at very low light levels, (the equivalent of ~ 5 photoelectrons per image element) and consequently doesn't have the low threshold problems of photographic plates. Another vidicon system is that of McCord and Westphal at Caltech which employs a silicon-diode-array as the target. The device has a very high quantum efficiency (85% at $\lambda 5000$, 30% at $\lambda 9000$ and 6% at 1.1 μ) with individual elements spaced 15 μ apart in a 256×256 element array. However the minimum detectable signal is rather large (about 1000 photons) and something equivalent to reciprocity failure is present. The dark current of a cooled system is $\sim 5\%$ of the maximum signal. However a 1% photometric accuracy after suitable calibration is claimed as is the ability to integrate for several hours. More recently a silicon intensifier tube has been added to overcome the rather large threshold problem, i.e. the photoelectrons emitted by the photocathode of the image tube are accelerated directly onto the silicon-diode-array target. It has been used successfully in narrowband 2 dimensional scanning of Mars and at the 100 in. coudé where the gains over interferometric techniques are claimed to be as large as a factor of 5. The gain over conventional photographic plates and scanners is of course very high. Yet another system is the image-dissector scanner (IDS) developed by Wampler and Robinson at Lick Observatory. This uses the phosphor of a three stage image-tube as a short-term storage element which is scanned by an image-dissector photomultiplier tube with a resolution element of $37 \times 250\ \mu$. Two thousand such elements are scanned every ~ 4 ms with sky and star spectra being scanned alternately. The output goes directly into an on-line computer for immediate processing as well as onto tape for later data treatment. It is presently being used with a Cassegrain spectrograph on the 120-in. with a resolution of 2–3 Å. down to 22nd mag. McNall *et al.* have coupled such an IDS system to an échelle spectrograph (2 Å mm^{-1}) and claim speed gains of ~ 100 over a conventional slit and a single photomultiplier at a resolution of 0.1 Å. The system is now essentially an area scanner with specific scanning along the spectra of each order.

The advantages and potential advantages (potential, since only the Wampler system is in regular operation) of these systems for stellar atmospheres are quite clear: they should allow high resolution, high accuracy line profiles to be measured in much fainter stars than at present. They should allow lower resolution spectra to be obtained of much fainter stars, e.g. in globular clusters, Magellanic Clouds, etc. for general abundance studies, etc. Finally they convert small telescopes (i.e. ~ 1 m diameter) into the equivalent of large telescopes with conventional coudé systems so that many more observatories can get involved in spectroscopic research. What they could or should do is another question which we will touch upon later but clearly the large increase in sensitivity opens up a whole new world of problems.

Other instrumental developments which to me seem of great future importance are the intensity interferometer of Brown and coworkers and the speckle interferometer of Labeyrie and coworkers which permit the measurement of stellar diameters. The Brown instrument has been in operation for several years now and has produced the largest number (~ 20) of stellar diameters. The technique relies on the fact that the statistical fluctuations of photon intensity also contain a wave interaction term resulting from beats between adjacent frequencies. The maximum resolution of the present 200 m baseline is $\sim 5 \times 10^{-4}{}''$ but the small collecting area now limits the measurements to stars brighter than $V = 2.2$ mag. However a proposed scheme would increase the collecting area as well as making other improvements to extend the magnitude limit to $\sim V \simeq 6.5$ mag. The Labeyrie system makes use of the speckle pattern of a stellar image which is an interference effect caused by random phase and amplitude perturbations impressed upon the incident wavefront by atmospheric turbulence and telescope aberrations. An image tube camera is used to record stellar images with very

https://doi.org/10.1017/S1539299600001866 Published online by Cambridge University Press

short exposures (1 to 100 ms). Two-dimensional Fourier transforms of each image are co-added and compared to those of a standard star to obtain the two-dimensional equivalent of the visibility curve obtained by Michelson and Pease. The data reduction and handling appears to be a real problem at present but a practical resolution limit of 0″.01 for $V=9$ mag. is claimed for the 200-in. Ten stars have been measured so far and confirm the measurements of Michelson and Pease using the Michelson interferometer. The technique also allows the determination of stellar oblateness (none detected yet), limb darkening, and separation of close binaries as well as surface detail (non-radially symmetric). The most exciting result has been the measurements of α Orionis as a function of λ and of o Ceti as a function of λ and phase. Both stars are larger in the blue which suggests that continuum scattering is important for cool stars. Mira also has a change in size as a function of phase as shown in Table I.

TABLE I

(a)	α Ori.	$\lambda =$ 4200		dia = 0″.069
		4880		0.067
		5700		0.055
		7190		0.052
		10400		$\leqslant$ 0.050
(b)	o Cet	$\phi = 0.09$		$\phi = 0.38$
		$V=4$		$V=7$
	$\lambda =$ 4500	dia = 0″.070	$\lambda =$ 6700	dia = 0″.062
	5150	0.057	7000	0.058
	7500	0.051	7500	0.055
	10400	$\leqslant$ 0.050	7500	0.055

Clearly the field is just beginning but already a marked improvement in sensitivity seems possible, namely the use in two-dimensions of one of the television devices discussed above to replace the present photographic system. It is claimed that spatial structure will be accessible for objects as faint as 20th mag. with the 200 in. (down to its diffraction limit of $\approx$0″.01 to 0″.03) which has perhaps even more importance to non-stellar astronomy than to the narrow field of stellar atmospheres. However objects with circumstellar material certainly fall into this domain and such high resolution capabilities could in principle tell us a great deal about the structure of that material.

3. Observations

In the area of actual observational problems for the future it is of course extremely difficult to say where our interests, calculations, instrumentation and finances will take us in the next ten years. Among these we may cite the following:

(a) The general acceptance of non-LTE representations for the stellar atmosphere along with the inclusion of previously neglected transitions involving two electrons. Such calculations have been (Mihalas and coworkers) very successful in explaining away several so-called selective excitation effects in early type stars. In general the departures from LTE are largest for stars of highest temperature and luminosity, and their effects on abundances and microturbulent velocities can be quite large.

(b) The extension of chromospheric studies to stars other than the sun by Wilson and coworkers with the discovery that the Ca II K chromospheric emission is both a function of the age of the star (from the total flux) and of its visual luminosity (from the width of the line). Thus the presence of chromospheres has been confirmed for most F, G and K stars but virtually no one has included the consequent effects in their model atmosphere calculations.

(c) Evidence for the presence of velocity fields and mass-outflow has been steadily accumulating and now with the striking ultraviolet results (i.e. the P Cygni type profiles in the resonance lines of early type supergiants) mass-outflow is a well established phenomenon common to all luminous stars as well as Miras and pre-main sequence objects. Velocity gradients in the photospheres of supergiants have also been deduced for micro- and macroturbulence.

(d) The discovery of infrared excesses in stars covering a wide range of spectral types which has provided direct evidence for circumstellar material in the form of ionized gas and/or dust particles. The presence of dust has usually been deduced from the infrared energy distribution which often resembles that of a black body of very low temperature ($\lesssim 1000$ K) even though the photospheric temperature is much higher. Free-free emission can usually account for most of the other observations although a large group of objects exists for which the distinction is not so clear. Further evidence for circumstellar material has been the detection of polarization and its variation as a function of wavelength in certain groups of objects with infrared excesses. More recently radio emission has also been detected from some of the more extreme infrared excess objects.

(e) The detection of ultrashort variability in a variety of stars. The periods range from 33 ms for the Crab pulsar to 10's of seconds for many old novae, dwarf novae and similar objects.

(f) The ultraviolet (space) variability of α_2 CVn. Here the amplitude of variation (periodic) is modest ($\lesssim 0.10$ mag.) in the visual, decreases to zero in the near uv and increases again to a few tenths of a magnitude in the far uv but 180° out of phase. This seems explicable in terms of blanketing effects but certainly provides another important handle on atmospheric structure.

(g) The revision of f-values and their resultant change on the solar iron abundance.

(h) Identification of X-ray sources with stellar objects.

(i) The increase in high resolution spectroscopy in the infrared with its resultant determinations of crucial isotope ratios.

We can continue to list such items ad infinitum but it may be more worth while to look at a few of them in more detail before making any comments about the future of observational stellar atmospheres. The role of non-LTE calculations is clearly a very important one for the determination of abundances and other atmospheric parameters. Just how important can be seen from the recent work by Mihalas and collaborators for early type stars. We might first recall some of the problems resulting from conventional LTE analyses of O and B stars:

(1) a helium abundance of $Y=0.15$ to 0.2 and a microturbulent velocity of $\xi_t \simeq 15$–20 km s^{-1} is required with $\log g=4.5$ (from hydrogen) to get agreement with the observed equivalent widths.

(2) Magnesium abundances are up to ten times the solar value with the most discrepant equivalent widths being 4–5 times too small even with very large ξ_t.

(3) The predicted hydrogen line strengths decrease with temperature, the He I lines disappear and the line profiles do not have deep enough cores.

The non-LTE calculations eliminate all of these difficulties and point out some very interesting general conclusions that observers should keep in mind. These are the following for O and B stars:

(a) the non-LTE abundance is decreased with respect to the LTE value.

(b) the observed behavior of equivalent widths with effective temperature is more closely reproduced.

(c) the microturbulence parameter is reduced, often even to zero, and is likely to be further reduced by including UV line blanketing.

(d) the departures from LTE are largest for low gravity and high effective temperature.

(e) the departure from LTE can be large for weak lines as well as strong ones contrary to the often made statement that non-LTE effects are not important for weak lines.

The later type stars have not been so thoroughly investigated because the required calculations are enormously complicated. However, to me, the trend is clear: curve-of-growth analyses based on LTE models cannot and should not be considered as realistic until they have been shown to be so on the basis of non-LTE calculations. Until that time we must hold suspect the abundances derived from such models.

Another aspect of recent non-LTE work has been the inclusion of all possible transitions into the equations of statistical equilibrium. Chief among the previously neglected processes are those involving two electrons, i.e. autoionization, dielectric recombination, two electron transitions, etc. One example should suffice to illustrate the importance of including such transitions. In the Of stars there has long been the unsolved problem of the origin of the N III 4634, 40, 41 lines which appear in emission whereas the lines from the next cascade down are in absorption. The Bowen fluorescense mechanism has often been proposed as the solution but the intermediate O III lines are not observed in emission. It also requires a large He II flux so that the He II 4686 line strength maybe expected to correlate with the N III lines but this is not observed. Mihalas, Hummer and Conti have shown that the dominant depopulation of the lower level ($3p$) is via a two-electron transition to $2p^2$ which is so efficient that $3p \rightarrow 3s$ remains in absorption. Also the population of $3d$ is dominated by dielectronic recombination. The net result is that $3d \rightarrow 3p$ produces the three emission lines observed. However the present calculations with a plane-parallel atmosphere do not predict the observed total fluxes but do predict the qualitative behavior of the emission strength. Clearly an extended atmosphere is needed to increase the emission flux. Similar calculations also seem to explain another 'selectively' excited line C III 5696. The lesson here is very clear: all processes must be included in the calculation of level populations before worrying about selective excitation mechanisms or other fancy processes.

Now what is the role of the observer in all this? Sadly enough the basic data required for checking the predictions and the models are usually lacking. Continuous energy distributions in the optical are usually available and in the near future the ultraviolet region will be well covered as well. However line profiles determined to a precision of 1% are really the final comparison although accurately determined equivalent widths are also very useful even though they throw away all information about the profile. The non-LTE calculations also make specific predictions about expected emission line strengths for the other transitions involved in the so-called 'selective' processes and yet no accurate (i.e. to 1%) total flux measurements exist. This is all of course with regard to the hotter stars but the same basic lack of data also exists for the cooler stars where the theoretical work is much less developed. The measurements would not involve any fancy non-existent equipment but no one seems to be doing anything in this area. I strongly suggest that the observers get busy.

Another area of future interest is the problem of velocity fields in stellar atmospheres, i.e. from microturbulence and macroturbulence to large scale outflow. The microturbulent velocity is one of the most mysterious parameters that has arisen in the analyses of equivalent widths (and line profiles) for stellar abundances. It was introduced many years ago by Struve and Elste to account for the additional broadening that was present in the observed absorption lines, i.e. the thermal Doppler broadening was not large enough to produce the observed line widths. No physical explanation of this parameter was given then nor has any satisfactory explanation been given since. It seems that everyone derives a value for it but nobody knows what it is. At worst it seems to be nothing more than the 'Cook's variable constant' of undergraduate physics labs to make the theoretical and observational results agree. At best it could be some kind of small-scale turbulence related to the convective motions in stars like the Sun. So the outstanding question is, 'What is microturbulence?'

Since most people are familiar with the history of microturbulence I need not repeat it here other than to recall to you that it is usually derived from curve-of-growth analyses under the condition of making the dependence of element abundance on equivalent width as small as possible. This dependence is in the sense that the stronger the line the greater the inferred abundance. In extreme cases the abundance can vary by a factor of 10 from weak to strong lines and deducing a model that will predict entirely consistent abundances is almost impossible. The microturbulent parameter ξ_t is smallest in dwarfs (~ 5 km s^{-1}), larger in giants (~ 10 km s^{-1}) and largest in supergiants ($\gtrsim 20$ km s^{-1}). Its effects on the derived abundances are appreciable: changing ξ_t by a factor of 2 can change the abundance by a factor of $\lesssim 5$. This large sensitivity comes about because ξ_t determines the position of the flat part of the curve-of-growth. Even in the Sun there seems to be a systematic increase in abundance from center to limb and from weak to strong lines by a factor of two. Some light can be shed on this mysterious parameter by the recent work of Smith on six sharp-lined A stars. He finds that ξ_t peaks around 4 km s^{-1}. in mid to late A stars even after all corrections are applied. But even more importantly he suggests that the much higher earlier estimates could arise from the following:

(a) the revision of the f-value scale produces a decrease of $\sim$1 km s^{-1} in ξ_t.

(b) errors in broadening (e.g. in the damping parameter **a**) can give rise to spurious ξ_t: a factor of 7.5 in **a** produces a 1.25 km s^{-1} increase in ξ_t.

(c) a 1 kgauss magnetic field mimics an increase of $\sim$ km s^{-1} in ξ_t.

(d) the equivalent width depends on the dispersion of the spectograph, i.e. it is $\sim$30% larger at 8 Å mm^{-1} than at 2.7 Å mm^{-1} and a factor of $\sim$2 larger at 16 Å mm^{-1} than at 2.7 Å mm^{-1}. A factor of 2 increase in equivalent width is equivalent to an increase of 3 km s^{-1} in ξ_t. Finally he points out that ξ_t is also reduced by the proper inclusion of line blanketing effects in the model atmosphere, something which is not very often done. Similar results can no doubt be derived for cooler stars as well.

We should also note a very interesting trend in the values of ξ_t that appears with the increasing complexity of the model atmosphere. As mentioned above one of the consequences of the non-LTE calculations for early type stars is a reduction of the value of ξ_t. For hydrogen and helium ξ_t goes to zero; for Mg some residual ($\sim$4 km s^{-1}) microturbulence still seems necessary although a slight increase in abundance could get rid of it. The Ca II K line in B stars still requires a few km s^{-1}. Again the complete inclusion of ultraviolet line-blanketing would act to further reduce ξ_t. The same comments can be made about other spectral types but the calculations are not nearly so complete. However the trend is clear: the more complete (and hence the more accurate) the model the smaller the value of ξ_t. Such a result seems only to emphasize the *ad hoc* nature of microturbulence and makes an innocent bystander wonder about its physical significance. It seems very likely that it will either disappear or decrease drastically in model atmospheres in the future.

There may also be another explanation for the large values of ξ_t derived for stars more luminous than dwarfs. The extended atmospheres of supergiants provide us with the interesting possibility that microturbulence may be connected to a general velocity field, i.e. a gentle expansion of the atmosphere. Numerous investigators (e.g. Rosendhal and Wegner, Aydin, Groth, Williams, Lamers, Warren and Peat, Wolf) have arrived at more or less the same conclusions regarding the atmospheres of A and B supergiants:

(a) the atmospheres seem to be in expansion, and a radial velocity gradient is present, e.g. from 5 to 60 km s^{-1}.

(b) the microturbulence correlates with the radial velocity and a gradient is necessary to fit the observations, i.e. ξ_t is small at large optical depth (5–10 km s^{-1}) and large (20–30 km s^{-1}) at small optical depth.

(c) these gradients in v_r and ξ_t are variable with time.

(d) ξ_t increases with luminosity and decreases with lateness of spectral type.

We also note that Karp has compared curves-of-growth computed with and without velocity fields and finds that a curve with $\xi_t=0$ and a small velocity gradient ($\Delta v_r = 10$ im s^{-1}) is identical to one with no velocity gradient and $\xi_t = 5$ km s^{-1}, until the damping part is reached where a lower value of **a** is mimiced. Absorption profiles produced in the presence of a velocity gradient would be asymmetric but a small amount of microturbulence (~ 30 km s^{-1} as observed) would probably suffice to smear out the asymmetry so that it would not be noticed. The resultant effect could be a misinterpretation in terms of microturbulence. The present data however are so meager that a full-fledged observational attack on this problem is long overdue. Griffin's suggestion of using terrestrial absorption lines as wavelength standards should be explored further and put into use to investigate the velocity fields in normal stars and giants as well as in supergiants. The intrinsically higher accuracy of Griffin's technique should permit measurements of radial velocities to an accuracy at least 10 times greater than at present. Consequently there is no excuse for not making the observations necessary to elucidate the true nature of microturbulence. A fruitful area to also explore is the behavior of ξ_t in those stars for which we already know something about the velocity field e.g. pulsating stars such as the Cepheids. Preliminary work here indicates that the picture is still very murky. Van Paradijs has obtained both v_r and ξ_t as a function of phase for 9 cepheids and finds that ξ_t is largest when the star is most rapidly contracting (e.g. amplitude 2–6 km s^{-1}) but that it is constant for the opposite half of the cycle ($\sim$3–5 km s^{-1}) contrary to what one might expect if indeed the velocity gradient were solely responsible for the microturbulent parameter. This complication of course serves only to make the problem more interesting and points out very clearly that the next phase of stellar atmosphere research (both observational and theoretical) must be the inclusion and investigation of hydrodynamic effects, i.e. the assumption of hydrostatic equilibrium must be dropped.

The observational prospects here are enormous since the subject of expanding and consequently extended atmospheres has barely been touched. This naturally leads us to the third and final subject that I want to say something about, namely circumstellar matter and by this I mean anything that is in the immediate vicinity of the star and hence very likely intimately connected to it in one way or another, e.g. via mass loss or dynamical collapse or whatever. The observations cover the entire wavelength range accessible to observers, i.e. from X-rays to radio waves. X-ray radiation has been linked to several close binaries with possible mass exchange which results in in X-ray production when the material falls onto a companion neutron star or other very condensed object. In the far UV the P Cyg profiles of resonance lines in OB supergiants suggests high-velocity ($\gtrsim 1000$ km s^{-1}) outflow whereas no evidence for it is observed optically. At optical wavelengths in other stars similar P Cyg profiles and other emission lines have long been interpreted in terms of outflow and circumstellar material, often of great extent. Also displaced absorption lines of Ca II and other elements in late type giants and supergiants led to the idea of low velocity outflow for these stars. The infrared observations have been a great revelation in the detection of infrared excesses from a large variety of stars and have raised many interesting problems. The standard explanations for the excesses involve either thermal reradiation from circumstellar dust grains or free-free emission from ionized hydrogen. Dust around cool stars such as M type supergiants seems quite acceptable but dust around hot stars (such as the Ae and Be stars associated with nebulosity) present the question of not only the survival of the dust but its formation or origin. Here an extreme example might be the Wolf-Rayet stars of type WC9 which have black body peaks corresponding to ~ 1000 K whereas the star itself has an effective temperature in the range 20000 to 30000 K. The emission line widths indicate velocities of expansion of the order of ~ 500 km s^{-1} in the region close to the star (i.e. $\lesssim 30$ stellar radii) but no information exists as to the velocity fields in the region of the dust. Is the dust formed from the ejected material or is it just left over from earlier phases of star formation? How is this possible in the presence of a hot star? Some clues as to the nature of the particles can be provided by high resolution infrared spectroscopy but so far only the diffuse 8–10 μ feature of silicates has been found. Polarization measurements also can serve to distinguish between free-free and thermal re-emission as it seems to have done for the classical Be stars and the M stars. The situation for other stars is very confused at the present time and more measurements are sorely needed.

Microwave and radio measurements have been successfully made for a number of sources. Radio frequency radiation has been detected on the 10–100 mfu level in a number of early type stars with very large infrared excesses and strong emission-line optical spectra. These additional frequences provide a close check as to the nature of the infrared emission (e.g. in MWC 349 it is impossible to get as much infrared radiation as is observed from free-free emission that would be consistent with the radio measurements; dust must be present). As sensitivities increase to lower and lower levels the number of detections should increase dramatically so that similar calculations can be made for other stars as well. OH maser sources have also been mapped out in a $\sim 2 \times 2''$ area around stars like NML Cyg (a late type supergiant) by means of very high resolution interferometry. Several such sources are present and may be connected to an earlier explosion of the star and/or an ejection of material from its surface (Herbig). What the role of such masers may be with regard to the stars with which they are associated is however very unclear to say the least.

We have listed a few of the observations made in each wavelength range that lead to the conclusion that circumstellar material must be a very common phenomenon among a large range of stars. We can generalize a bit and lump them all together in a hypothetical picture of a star. First, surrounding the interior we have the photosphere, chromosphere and corona for stars like the sun. Second, for the objects mentioned in this section we probably still have something akin to the chromosphere and corona but we would call it an extended atmosphere or envelope. It is here that the evidence for mass outflow and large scale velocity fields must be produced. Still further there must exist the region of dust formation and/or destruction i.e. the region responsible for the thermal re-emission. Finally one might run into the OH masers, compact H II regions, etc. but where these are located is not at all clear. In addition many of the objects mentioned are very young and theoretical calculations indicate that we shodul be observing infalling material rather than outflow. Perhaps the speckle interferometer in its TV coupled mode can actually map out the velocity fields of the circumstellar material by producing highly resolved spatial maps in different parts of an emission line, i.e. at different velocities. At present we really do not know anything about the velocity fields involved in the vicinity of the star; is the matter really coming in or going out? As far as the stellar atmosphere problem is concerned I now see it expanded in two directions:

(1) the inclusion of velocity fields, and

(2) the interaction of radiation not only with the photosphere but with the entire gamut of circumstellar material including the grains themselves.

The observations needed to understand these two areas are just beginning to be made in a systematic fashion after the initial spectacular discoveries. However the crucial questions have yet to be asked and the direction of observational attack is very unclear. Nevertheless it is in these two areas that I think our most creative efforts will pay off with the largest dividends not only in understanding the various interactions involved but also in understanding the basic process of star formation itself.

4. Conclusions

In concluding this talk I realize that what I've really presented here is more of a status report of where observational stellar atmospheres are today and not a prediction of the future. The future observers' task lies in several areas:

(a) A general mopping-up type of operation such as the extension of NLTE models to cooler stars and the accompanying refinement of data that is needed to do the job. This alone will keep many astronomers busy for many years.

(b) A full-fledged effort in subjects that have only recently opened up because of new observations usually made with new instrumentation. The problem of circumstellar matter including radiative transfer, velocity fields, mass-loss, grain formation and destruction, and other peculiar phenomena such as OH masers fit into this category. Imaginative new techniques and ideas will be needed to help solve the questions already raised by the very incomplete data presently at hand not to mention the ones we don't even know about yet.

(c) A continuing effort in instrumental development designed to improve sensitivity, accuracy, data handling ability, etc. Accompanying this there must also be a matching sophistication of data reduction techniques in order to avoid being inundated by infinite amounts of data that cannot be adequately analyzed. In addition there must continue to be the development of new and radical ideas which of course are impossible to predict in advance (the speckle interferometer is a good example) but which often can revolutionize an entire branch of astronomy. We should always keep our minds open and receptive to such ideas so that they have a chance of being properly developed. What we should not do is to smother them in conventional objections simply because they are different or because they are not readily understood by most of us. This of course applies to theoretical stellar atmospheres as well as observational ones and perhaps should be a guide for all future work.

The three areas of course go along hand in hand since what is to-day's exciting new discovery is tomorrow's mop-up routine type of work. All three are needed to maintain progress but a strong interaction among the three is very vital and absolutely necessary. Otherwise the subject of stellar atmospheres will stagnate exactly in the manner in which some alarmists have claimed is already the case. This is not true now and shows no sign of becoming true in the future. There is a great deal of exciting new work to be done.